ARMY DIGITAL SYSTEMS AND VULNERABILITY TO CHANGE BLINDNESS

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ABSTRACT

The failure to detect what should be a fairly obvious visual change is known as "change blindness." Change blindness is most likely to occur if visual attention is diverted from the location of the change when it occurs. As Army digital systems become more multifunctional, their visual displays more complex, and their operators responsible for multiple tasks, it becomes more likely that those operators will suffer from change blindness. In this experiment, visual change detection using the Force XXI Battle Command, Brigade, and Below display was investigated. Participants were instructed to monitor the display and report changes they noticed as quickly as possible. They were also periodically instructed to conduct certain tasks with the system, such as performing a circular-line-of-sight analysis or sending a text message. When occurring alone, map icon position changes were, on average, detected 83% of the time; however, when those changes were simultaneous with the closing of a task window, they were detected, on average, only 40% of the time. Besides documenting the degree of change blindness that can occur, this experiment demonstrated a weak effect of change distance on detection of icon position changes. Detection of position changes may be aided by the availability of reference points in the display. It is suggested that as Army digital systems become more complex they will need to log changes and deliver alerts in such a way that they can be conveniently and efficiently reviewed without adding to workload.

1. INTRODUCTION

Recent research results indicate that people often fail to notice changes in visual displays if the change occurs at the same time as some other visual event, such as a screen flash, window relocation, or even an eye blink. This failure is particularly likely if visual distractions draw the observer's attention away from the location of the change. The failure to detect what should be a fairly obvious change is known as "change blindness." Because the Army is increasing its use of digital systems, it is important to know whether (and when) users of these systems may be vulnerable to change blindness. According to what is known about change blindness, as the complexity of a visual display system increases, so too does the possibility that important changes in visually presented information will be missed. The present research evaluated the degree to which the detection of icon position changes on a military command and control system are vulnerable to change blindness.

The system used in the research was FBCB2 (Force XXI Battle Command Brigade and Below). FBCB2, a fielded Army information system, is used across echelons from vehicle commanders up through battle command staff. It provides on-the-move, near real-time command and control information relevant to each of the battlefield functional areas and supports situational awareness. We asked University of Central Florida students to monitor the FBCB2 screen for changes. Whenever they noticed a change, they were to use the computer mouse to click on a response bar on the screen. Clicking on the response bar then opened a new window with a list of options. Observers were instructed to select the option that best described the change they observed (e.g., a blue icon changed position). After making their selection this window closed and observers went back to monitoring for changes.

The focus of this experiment was on icon position changes, although other changes were made to obscure this from the awareness of participants. The experiment was intended to address whether detection of icon position changes depended on the size of the position change, the location of the icon at the time of the change, and the impact of another simultaneous event (window closing). In a previous experiment Durlach and Chen (2003) found that the occurrence of a task window closing simultaneously with an icon change produced significant change blindness for the icon change. However, in that study we were unable to document whether detection of all types of icon changes were equally susceptible to this distraction. Therefore in the present study, the aim was to test the degree to which detection of position change is vulnerable to this form of distraction. Durlach and Chen (2003) also found that detection of icon position changes (without distraction) was sensitive to the size and starting location of the change. In this experiment, these factors were manipulated more systematically than in the previous study.

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2. METHOD

2.1 Participants

The participants were 14 female and 7 male students from the University of Central Florida, who chose to receive either extra credit in a psychology course or $10 for taking part. Average age was 20.8 years, and all students said they used a computer daily, or a few times a week. They all had normal color vision as determined by the Ishihara test. All of the data for 2 participants, and some of the data for one participant was omitted from the analysis, for reasons explained below.

2.2 Apparatus

Two computers were used for the experiment. A laptop, was used to present an introductory tutorial, and a PC with a 15" color monitor, was used for the experiment proper. The PC enabled the use of a modified version of FBCB2 (v3.5.4). The modifications included a superimposed program that allowed for the collection of change detection data. Figure 1 illustrates how the system appeared. The size of the map portion of the display was 17.9 by 14.3 cm, and the map icons were approximately .7 by .7 cm. The Yakima map, provided with FBCB2 was used at 1x resolution.

When the participant observed a change they were to use the mouse to click on the response bar as quickly as possible. This opened a choice window (and ceased all experimental timing). The participant chose from a list of 32 possible changes (grouped by type), with changes defined by color. For example, in the Move grouping, the list was Blue unit moved, Red unit moved, etc., and in the Affiliation change grouping the list was Blue unit changed to Green, Blue unit changed to Red, etc. Participants also were allowed to refer back to the tutorial if they needed to. The choice window also gave participants the option not to make any choice, in case they clicked the response bar by mistake. It also allowed them to report seeing a change not listed, by selecting "Other" and typing a description of the change in a text box. After making their selection, participants clicked on a response bar when they were ready to resume the experiment. This closed the choice window and resumed experimental timing.

The program recorded the time from when a change appeared on the screen until the participant clicked on the response bar (in the case of correct detections). When a change occurred, the participant could report the change up until the point at which a change of the same type was scheduled again. At that point, that change was considered missed. The average time available to detect a change was 150.8 s (median 57.5s), with a minimum of 8.1 s and a maximum of 1326 s. False alarms (reporting changes that did not actually occur) were also recorded.

The map was divided into 2 hypothetical regions, determined by lines dropped 25% of the way from each edge of the map. As illustrated in Figure 2, the center was made up of the middle 25% of the map; the remaining 75% constituted the periphery. A light blue "self" icon always appeared approximately in the center of the map; but was never changed. In addition, 4 other icons were located in the center region. These did not change after their initial appearance at the start of the experimental session. The positions of these icons are illustrated in Figure 2 (filled symbols). Besides these unchanging icons, there were between 4 and 6 other icons on the screen. Two of these (target icons) could appear anywhere, and change position or color (green to blue or blue to green). The remaining 4 icons made small one-dimensional and unidirectional moves within one of the peripheral sectors, as illustrated in Figure 2 (open symbols).

Periodically, pop-up windows appeared on the screen requesting the participant to perform one of 3 tasks using the FBCB2 system. These were: (1) perform a circular line of sight analysis, (2) set a periodic reminder, or (3) send a free-text message. These tasks will be referred to as distractor tasks (DTs). The participant responded to the popup window by clicking the OK button in the pop-up window, and performing the DT. This involved clicking on one of the buttons on the right of the FBCB2 display, and responding with information (either through button clicks or text entry) requested from a series of windows the FBCB2 system uses for these tasks. When open, the windows involved in the DTs covered various portions of the map display. The response bar (to indicate an observed change) was not operable during a DT.

The FBCB2 systems displays information on number of messages (FIPRs) received by the system, which was located both at the top and to the right of the screen (see Figure 1). These numbers were periodically incremented during the course of the experiment, and participants were instructed to report these in addition to the icon changes.
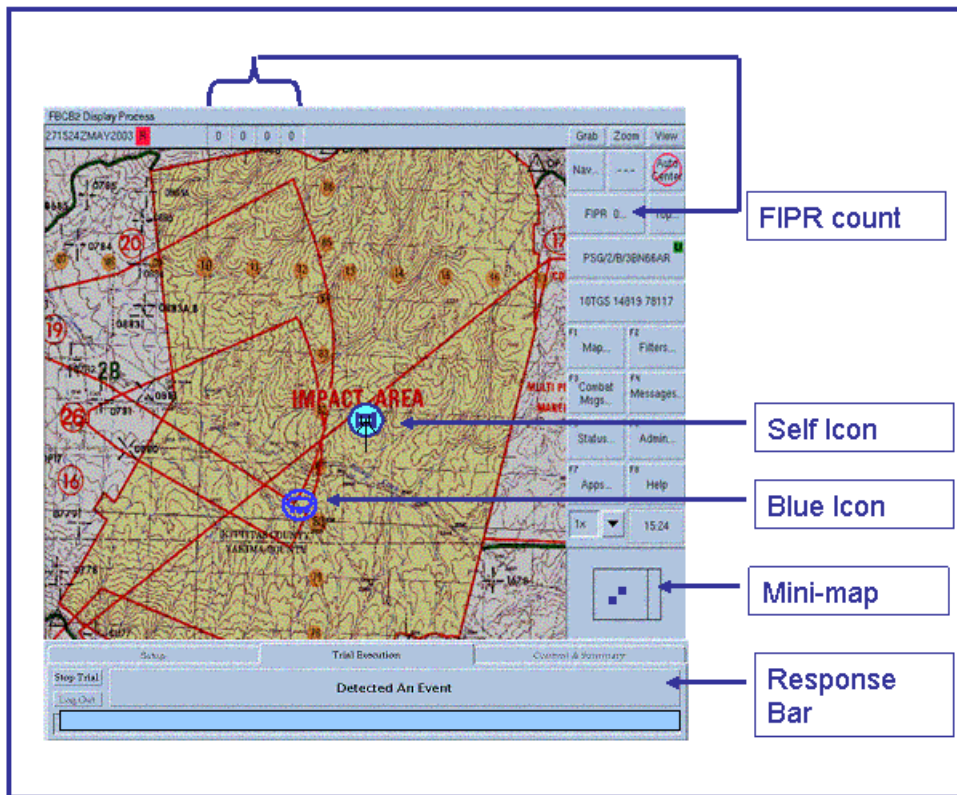
Figure 1. Layout of the FBCB2 screen, with certain features labeled. Participants were instructed to press the response bar when they observed one of the target changes. FIPR = Flash, Immediate, Priority, Routine.
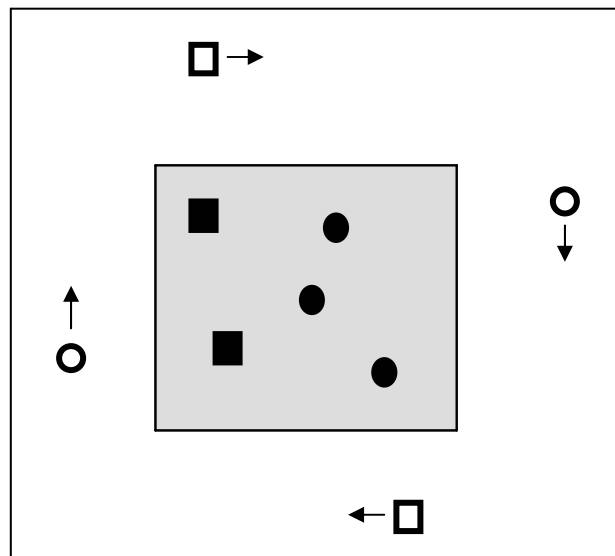

Figure 2. Schematic representation of the FBCB2 map, and the icons that were displayed continuously throughout the experiment (not to scale). Filled symbols represent icons that never changed. Open symbols moved in one direction only (as indicated by the arrows). Each time one of these icons moved, the distance was 0.05 of map height (vertical move) or width (horizontal move). Circular symbols represent blue icons and rectangular symbols represent green icons. In addition to these icons, 2 icons could appear, disappear, or change color (blue/green). The area referred to as the periphery is represented by the unshaded area in the figure, whereas the center is the shaded area.

2.3 Procedure

Participants listened to a brief taped explanation of the study, completed the Ishihara color blindness test, and then read and signed the informed consent form. This was followed by a period of training, during which the participant viewed a presentation that reviewed the purpose of the experiment, the FBCB2 display and icons, the changes they needed to watch for, and how to respond when they observed a change. They were also given instruction and practice at performing the DTs. After this tutorial, the participants performed 21 practice trials, which included 3 appearances, 4 color changes, 5 position changes, 3 FIPR count increases, 3 distractor tasks, and 3 disappearances. During practice the experimenter corrected any misunderstandings; and the participant was allowed to refer back to the tutorial slides as they wished. After training, the experimenter answered any questions and collected demographic information such as date of birth and computer experience. The experiment proper then began according to the parameters described below.

Participants were instructed to look for 5 general change types: icon appearance, disappearance, position change, color change, and an increase in the FIPR count. Only one of these changes ever occurred at a time, and changes always occurred at least 5 seconds apart.

During the course of the experimental session, there were icon position changes in which the distance moved was .1, .2, .3, or .4 of one map dimension, and anywhere between 0 and .15 of the other map dimension. The starting position of the changed icon, for each movement size (.1 - .4) occurred 8 times in the periphery and 4 times in the center (48 trials in total). The manipulated distance varied unsystematically between vertical and horizontal, subject to the constraint that icons that started in a peripheral sector always remained in the periphery, and icons that started in the center always remained in the center.

In addition to these trials, there were also trials in which a target icon shifted sector between center and periphery (18 trials) or vice versa (20 trials). The size of these movements was not systematically manipulated, but was at least as large as the .3 changes. Six of these sector shifts coincided with the end of one of the DTs. That is, the target icon change occurred simultaneously with the closing of the last window for the DT. A schematic representation of these trials is illustrated in Figure 3.

In order to place target icons in the required positions, and to make the movements of interest less predictable, target icons occasionally moved (4 times) between non-adjacent peripheral areas (e.g., from the east periphery to the west periphery). Target icons could also

appear, disappear or change color (16 times between blue and green).

Besides the target icon changes described above, there were 4 icons that moved only .05 of one dimension each time they moved (and never changed color or disappeared). These are represented as the open symbols in Figure 2. These changes will be referred to as path movement, as they represent the movement of the icons along a continuous, one dimensional path. In addition, FIPR message count was increased 12 times during the course of the session. Order of changes was semi-random and the same for each participant.
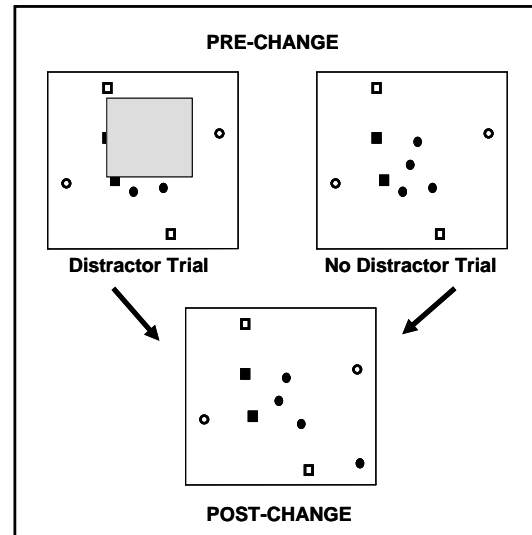

Figure 3. Schematic illustration of an icon position change after a DT (left; task window closes at the same time as the position change) and without a distractor (right).

3. RESULTS

Participants made 2 kinds of false alarms (FAs). Sometimes they selected change types that did occur during the experiment (e.g., blue icon position change), but that had not actually occurred since the last time they reported seeing it. Other times they selected change types that never actually occurred at all (e.g., yellow icon position change—there were no yellow icons used in the experiment). The median number of FAs for non-occurring event types was 5 (range 0 – 74). The data from the 2 participants who made these errors most frequently (74 and 17 errors), were excluded from the analysis.

To take into account the tendency to make FAs, for each participant, percent of correct detections was multiplied by 1 – (total number of FAs / total changes scheduled) for each type of change: position, color, and FIPR. The detection scores varied between 0 and 100 with 0 implying no correct detections and 100 implying perfect

detection with no FAs. To the extent that a participant made frequent FAs for a particular type of change, their detection score suffered. For a participant who made no FAs, the detection score was the same as percent correct detections. It should be noted that the results reported here for detection scores mirrored in every way the results found when percent correct detections were analyzed. All statistics reported were conducted via within-subject, repeated measures analysis of variance. All results reported as significant had probabilities less than .05, unless otherwise noted.

The main purpose of the experiment was to examine the effects of the DT on detection of position changes. These effects are illustrated in Figure 4. There was a significant effect of distraction on detection of icon movement across peripheral and central sectors, $F(1,18) = 31.01$. The mean detection score for this type of change was 78.8 when there was no distraction. However, when the same type of icon move occurred simultaneously with the end of a distraction task, mean detection score was only 37.2. Reaction time to detect these changes was also affected by distraction, $F(1, 14) = 29.79$. Without distraction, mean reaction time to detect position changes between the center and periphery was 2.58 s, whereas with distraction the mean was 7.93 s.

Figure 5 shows the results from within-sector moves, for which size was systematically manipulated. When the 0.1 – 0.4 sized moves were considered, there was a marginally significant effect of size, $F(3, 54) = 2.58$; $p<.065$); but no effect of location, $F < 1$. When the 5 sizes of peripheral moves were considered alone, the effect of size was reliable, $F(4,72) = 13.76$. A Tukey HSD test confirmed that path movement (size 0.05) was more poorly detected than any of the other within-periphery position changes. In addition, the within-periphery size 0.1 change was more poorly detected than the within-periphery 0.3 or 0.4 changes. For within-sector moves, reaction time failed to be affected significantly by size. Regardless of size, peripheral changes were detected somewhat faster than central changes. Mean reaction time was 2.10 and 3.07 seconds for peripheral and central sectors, respectively. This difference was marginally significant, $F(1, 17) = 3.96$; $p < .065$.
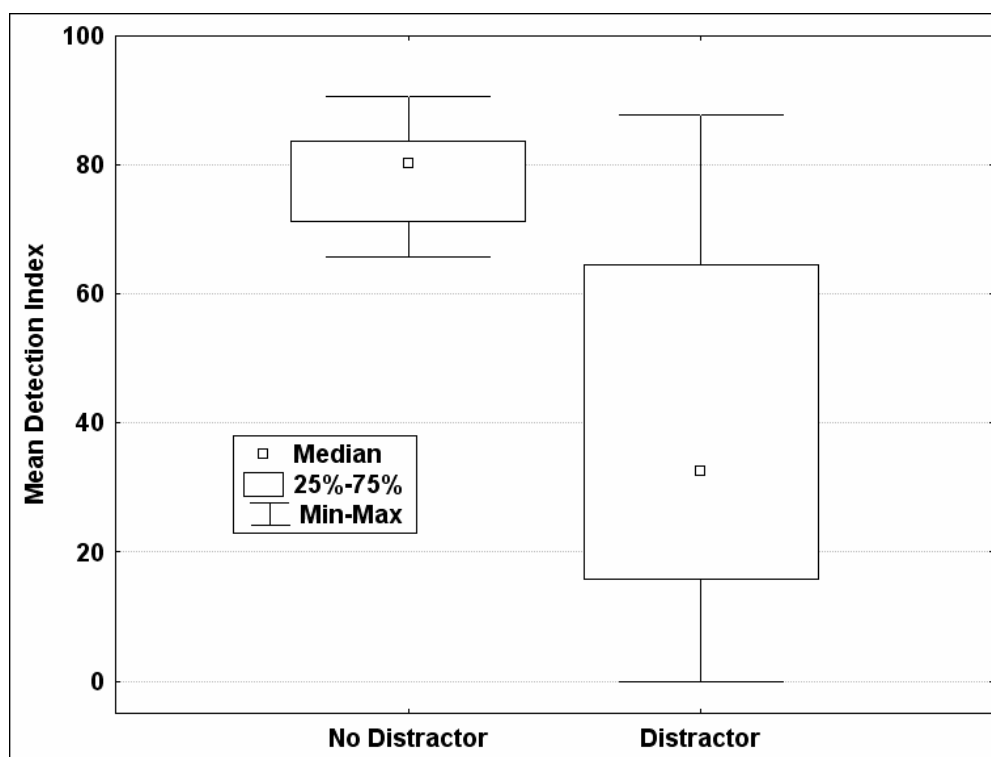

Figure 4. Distribution statistics (median, quartiles, and range) across participants' mean change detection index for cross-sector icon position changes. On No Distractor trials, an icon moved from the peripheral to the center sector, or vice versa. On Distractor trials, a task window closed simultaneous with the icon position change.
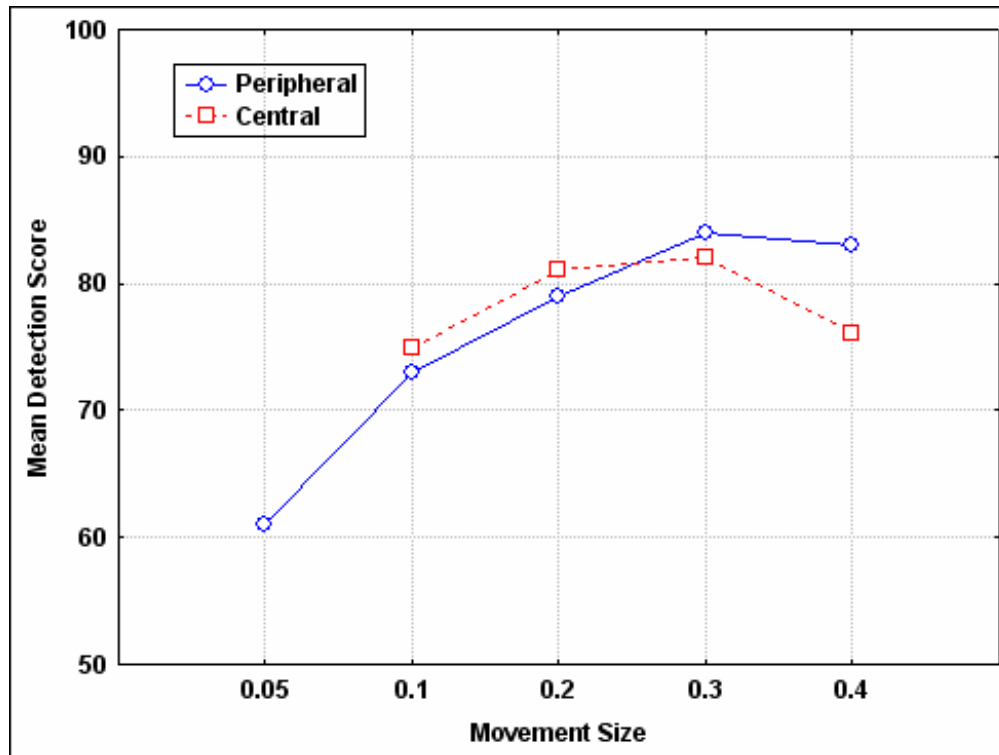
Figure 5. Mean detection scores for within-sector icon position moves as a function of size (horizontal axis) and location. Circles represent icons located in the periphery and squares represent icons in the center sector.

Detection scores for FIPR increment detections and color changes are illustrated in Figure 6, along with detection scores for position changes across center and peripheral sectors (without distraction), for sake of comparison. The FIPR detection data for one participant were excluded from the analysis, because this participant repeatedly responded to FIPR increments by selecting an incorrect option from the list.

There was a significant effect of change type, $F(2,34) = 4.56$. A Tukey HSD test indicated that detection for color changes was significantly below detection for the position changes. Mean reaction time to detect FIPR increments was substantially longer than to detect sector position changes or color changes. Mean reaction time to detect a FIPR change was 27.37 seconds, whereas mean reaction times to detect color and position changes were 9.36 and 2.32 seconds, respectively. A Tukey HSD test indicated that FIPR increments took significantly longer to detect than position changes; but neither differed from color changes.

4. DISCUSSION

The present results clearly replicated those of Durlach and Chen (2003) on the detrimental effect of simultaneous window closing on change detection. Participants were less than half as likely to detect an icon position change when it occurred simultaneously with the closing of a task window, compared to when it occurred in isolation. In the previous study, the effect of a DT was shown for multiple types of icon changes, but there was insufficient data to document the effect for specific change types. The present results document that position changes between sectors (central and peripheral) are vulnerable to distraction effects.

Previous research has shown that "mudsplats" occurring simultaneous with a visual change can interfere with detection of the change (O'Regan, Rensink & Clark, 1999). This involved the brief appearance and then disappearance of a rectangle or irregular shape on the display at the same time as the change. The present results indicate that merely the disappearance of a display feature (the task window) can have the same effect as the appearance and disappearance of an extraneous irrelevant shape. Interestingly, it has been found that interference from a mudsplat was a function of the meaningfulness of the change. The more meaningful the change was to interpretation of the displayed natural scene, the less mudsplats interfered with change detection (Rensink, 2000). It is possible that if the displays used in this study held more meaning for participants, less interference from the closing of the task window would have been observed.
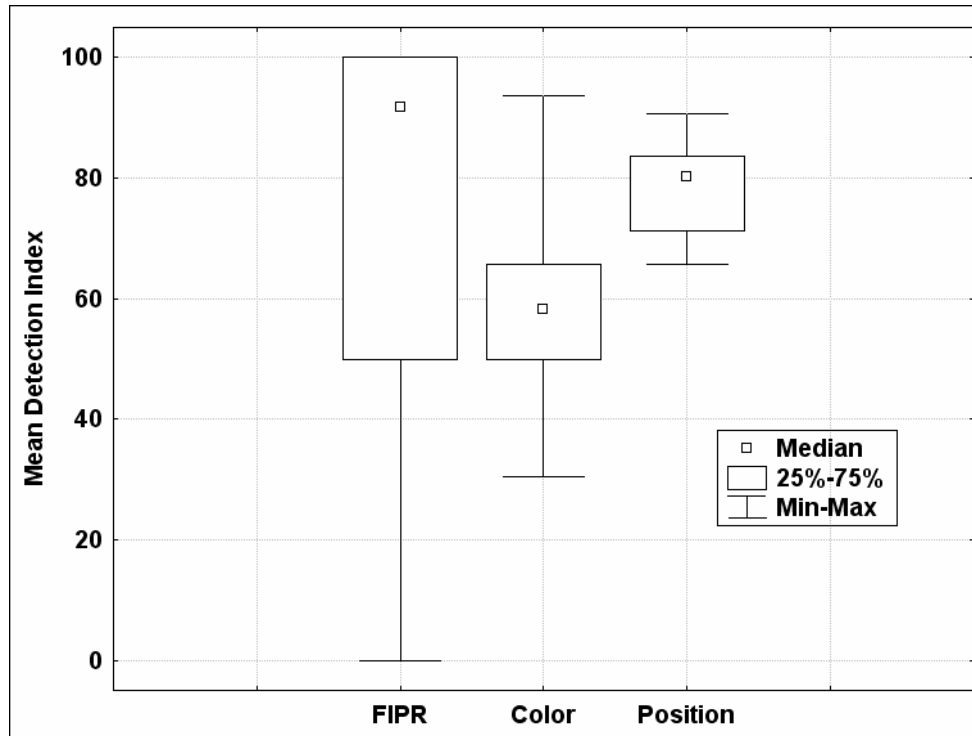
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Figure 6. Distribution statistics (median, quartiles, and range) across participants' mean change detection index for FIPR increments, color changes and cross-sector position changes (without distraction).

For the range of sizes examined, the present results provided only weak evidence for the effect of size or location on detection of icon position changes. While for within-periphery changes, sizes .3 and .4 were detected significantly more often than size .1, this effect was not sufficiently robust to produce a size by locationinteraction when the 4 sizes of change were compared across sectors (within-periphery vs. within-center). It should be noted that there were twice as many within-periphery moves than within-center moves. Standard errors of the mean were greater for the within-center moves (range .039 - .055) than for the within-periphery moves (range .023 - .03). Thus, this study may have lacked enough power to detect a size effect for within-center moves.

Display features of the present experiment might account for the weaker effects of size and location in the present results compared with those of Durlach and Chen (2003). In the Durlach and Chen study, the map contained only the (unchanging) self icon and one (changing) target icon. In the present experiment, the map contained the (unchanging) self icon plus 4 other static icons in the center sector, and the 4 path movement icons in the periphery. It is possible that these provided points of reference for the target position changes, making relatively small changes more detectable. That is, participants could detect not only isolated position changes, but also changes in icon patterns or groupings.

Path movement, which was the smallest sized position change, clearly did result in poorer detection performance than larger sized position changes. Poorer detection of path movement could have been due to the smaller size of that change, or to its unidimensional and unidirectional nature. Path movement was constrained to a horizontal or vertical path, whereas the larger position changes were unpredictable with respect to the direction of the change. It has been shown that when changes are very gradual, they can go undetected even though the incremental changes result in an obvious net change over time (Simons, Franconeri &Reimer, 2000).

Another reason for poorer detection of path movement than for the other icon position changes may have been the relative probability of the icons changing. Icons involved in path movement changed only by path movement, whereas icons involved in the larger position changes also changed color, and could appear and disappear. It is possible that participants learned to pay less attention to the 4 icons involved in the path movement. It has been shown that the relative probability of a change can affect its detection (Austen & Enns, 2000). Due to this confounding, the poorer detection of path movement can not necessarily be attributed to the small size of the movements.

Color and FIPR changes were included in this experiment to make position changes less predictable, and were not the primary focus of this experiment. It is notable, however, that detection of color changes was markedly inferior to that observed in Durlach and Chen (2003). Here, only 63.9% of color changes were detected, whereas in the previous study over 90% of color changes were detected. There are at least three possible reasons for the inferior detection of color changes in the present study. First, the present study included only color changes between green and blue, whereas Durlach and Chen (2003) employed changes among green, blue, yellow, and red. It is likely that some of these latter changes were more salient than that between blue and green. Second, the relative probability of a color change compared to other change types was lower in the present experiment, compared to the study of Durlach and Chen. This may have made participants less attentive to color over the course of the experimental session. Finally, as mentioned above, the map context was more complex in the present experiment, containing between 9 and 11 icons. For Durlach and Chen (2003), the map only contained 1 or 2 icons. It is possible that the greater number of icons required more shifts in attention, which interfered with color change detection (Rensink, 2000; Zelinsky, 2001). The average levels of position change and FIPR increment detection were comparable across experiments. Consequently, if display complexity was one of the reasons for poorer color change detection, it did not affect detection of the other changes in a similar way. As mentioned previously, multiple icons may have facilitated position change detection by providing reference points.

In summary, the present study demonstrated the dramatic effect that a simultaneous display event can have on detection of an icon position change, using an actual fielded military digital display system. Awareness of icon position changes is tactically highly important. One of the strongest potential benefits of digitized military systems is the ability to provide situation awareness with respect to the locations of out-of-sight friendly units, and thus to prevent fratricide. To the extent that important changes in icon position are not detected, this important benefit will not be reaped. More consideration needs to be given to the perceptual and attentional factors that influence change detection in the design of future military displays, with the implications these factors may have for achieving situation awareness. The differences found in the results of this study from that of Durlach and Chen (2003) suggest that some of these factors may be specific to particular display content (e.g., the effect of number of icons on position change vs. color change detection).

Display design improvements may not be sufficient to overcome the limitation of the human attentional system. In that case, the operator must be provided with aids such as alerts that ensure that critical changes are detected quickly. In addition, facility for reviewing display-event history should be provided. For example, the operator should be able to inspect the recent history of a specific entity, be able to review a log of all recent changes, and/or replay particular display changes in faster than real time. For a further discussion of this issue, see Durlach (in press) and Durlach & Meliza (2004).

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